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<p>SDC</p> <p>SOLENOIDAL DETECTOR NOTES</p>

INTEGRATED TRACKING CONFIGURATION I: SILICON AND WIRE
CHAMBERS

Gail G. Hanson

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GAIL G. HANSON

Indiana University, Bloomington, Indiana 47405 USA

ABSTRACT

A conceptual design of a tracking system for a solenoidal detector is presented. The tracking system consists of silicon pixels and microstrip detectors at small radius and wire chambers at larger radius. The goals for the tracking system design are to provide momentum measurements of all charged particles with p_T above a few GeV/c for $|\eta| \lesssim 2.5$ and to provide a fast trigger for such particles.

1. TRACKING SYSTEM DESIGN

The conceptual design for the tracking system is shown in Fig. 1. It consists of:

- A high-resolution two-dimensional pixel detector to aid in pattern recognition and detect separated vertices from long-lived particles and multiple p - p interactions;
- An array of segmented silicon microstrip detectors to provide a powerful pattern recognition tool even in the cores of jets;
- A wire chamber system to provide the high-precision momentum measurements and trigger information for high- p_T tracks.

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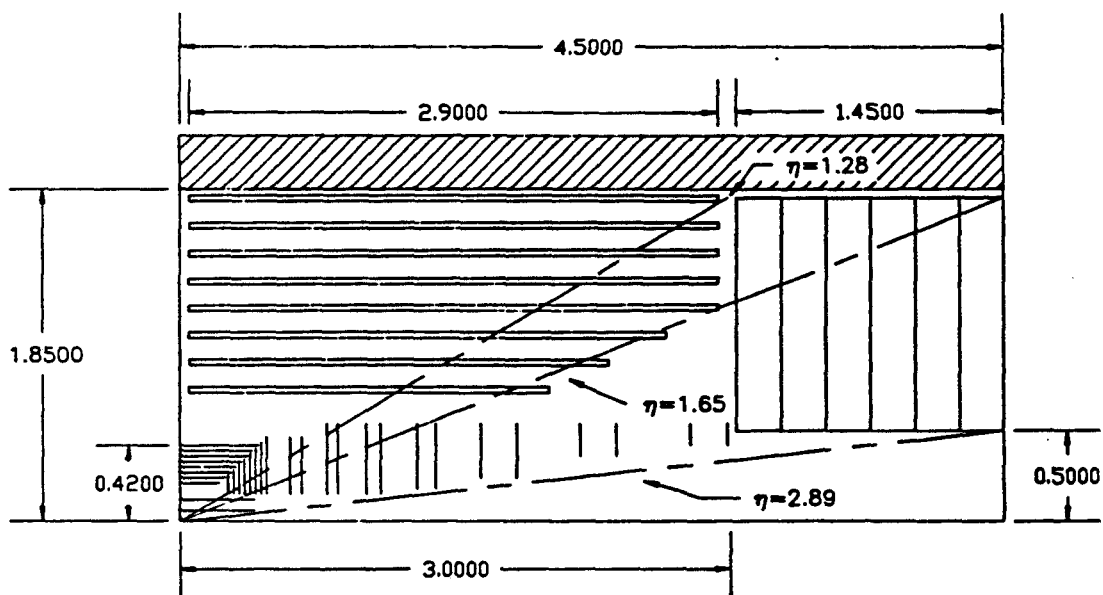


Fig. 1. Conceptual design for a pixel, silicon strip, and wire chamber tracking system for a solenoidal detector.

1.1. Pixel Vertex Detector

The pixel vertex detector¹ provides three-dimensional position measurements. It consists of two concentric cylindrical layers of pixel arrays within a radius of 10 cm from the interaction point and covers a pseudorapidity range $|\eta| \lesssim 2.5$, extending to $|z| = 40$ cm, where z is the distance along the beam line. The pixel sizes are expected to be $30 \mu\text{m} \times 300 \mu\text{m}$ in the ϕ and z directions, respectively. The position resolutions should be better than $10 \mu\text{m}$ in ϕ and $100 \mu\text{m}$ in z . The pixel arrays are shingled in both ϕ and z to provide complete coverage. The detectors will be about $300 \mu\text{m}$ thick, and a particle at normal incidence will traverse about 2% of a radiation length of material.

Because of the high particle rate, a "smart pixel" electronic system architecture is being developed to buffer information and read out events efficiently. A smart pixel signals when it is struck, stores the analog signal, and is read out only if it is associated with a valid trigger event. All circuit functions prior to readout are on the chip. The electronics will either be fabricated directly on the detector silicon or be part of a hybrid detector/readout system using indium bump-bonding technology.

1.2. Silicon Microstrip Detector

The silicon microstrip detector² covers the radial region from about 15 cm to 60 cm. The system consists of either double-sided detectors with axial strips on one side and stereo on the other or of many short strips aligned on a common sub-

strate. The detectors are arranged in superlayers, each with four measurements, in a cylindrical barrel region and also in planar endcaps. The intermediate angle detectors are spaced along the beam to a distance of nearly 3 m from the interaction point to allow good momentum measurement to large rapidities. About 32 m³ of silicon are needed. The supports must withstand both thermal and radiation effects and are expected to be made of either a graphite-based composite or beryllium. The goal is to have less than 5% of a radiation length of material at normal incidence.

Double-sided detectors with sizes up to 3 cm × 8 cm may be wire-bonded together to make larger units for electronic readout. The pitch in the barrel modules is 50 μm, whereas in the intermediate angle detectors the pitch varies with distance from the beam line. The heat load is about 1 mW/channel. Heat load is a major concern, and cooling by an evaporation-wick technique is being studied.

The spatial resolution is expected to be 15 μm, and the double-hit resolution is expected to be 150 μm. With such excellent position determination, the silicon microstrip system is expected to provide superior pattern recognition even in the cores of jets with p_T up to about 1 TeV/c. There are about 10 million channels in the system.

The pixel detector and silicon microstrip detector will have a common support system and will form an integrated high-resolution tracking device.

1.3. Straw Tube Central Tracking

Wire chambers are used for tracking for radii between 60 cm and 180 cm. They are suitable for spanning the tracking length needed for precise momentum measurement inside the large magnetic volume. They can also provide a fast trigger for tracks with p_T larger than some minimum value by the requirement that track segments in outer layers point back to the interaction point.

To meet the constraints imposed by radiation damage, current draw, chamber lifetime, gain reduction from large particle flux, hit rate, loss of data because of high occupancy, and pattern recognition in the complex environment, drift cells must be made as small as practical.³ Acceptable current draw and lifetime can be obtained with a 4 mm diameter straw tube chamber about 50 cm from the beam line; the other operating limits are somewhat less restrictive. This is also the practical lower limit on the diameter from considerations of track ionization length and electrostatic stability. Occupancy is minimized by use of a fast gas, such as a mixture containing CF₄.

Straw tube chambers are used in the central tracking region, $|\eta| \lesssim 1.5$. Eight layers of straw tubes are close-packed to form superlayers, as shown in Fig. 2. A

half-cell stagger between layers permits resolution of left-right and crossing-time ambiguities. Local track segments found in each superlayer are linked to form tracks.

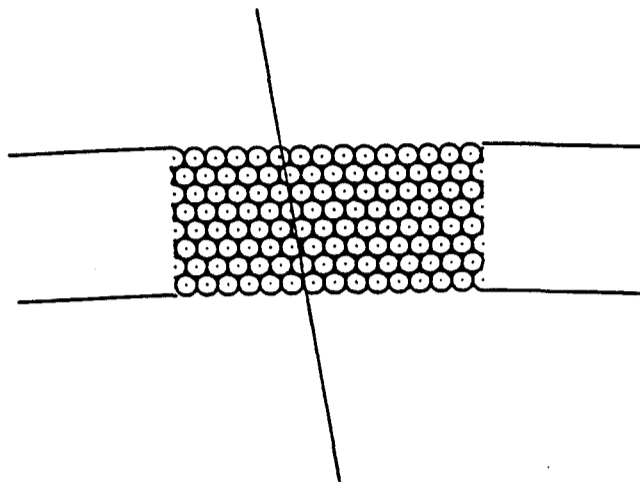
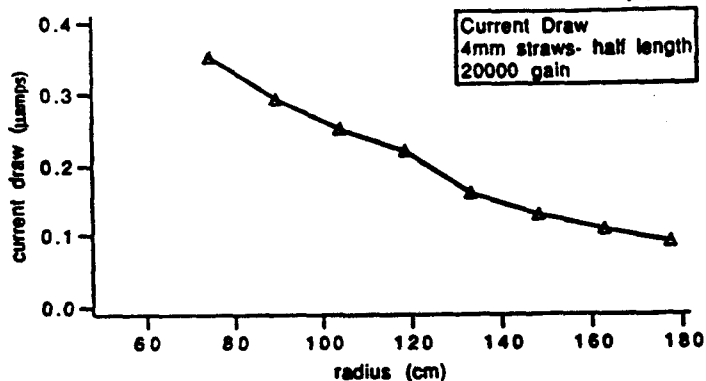


Fig. 2. Cross sectional view of the eight layers of a superlayer of straw tubes.

The coordinate along the wire is measured by means of small-angle stereo. With a spatial resolution of 100-150 μm per wire in the $r\text{-}\phi$ projection, the expected resolution in z is 2-3 mm. The superlayers are ordered axial, $\sim +3^\circ$, axial, $\sim -3^\circ$, etc., for a total of eight equally-spaced superlayers spanning $70 < r < 180$ cm, as shown in Fig. 1. The double-hit resolution is 2 mm. The maximum straw length is limited by signal attenuation to about 3 m. Straws up to 3.5 m long with wire supports inside the straws every 80 cm for electrostatic stability have been operated at the required voltage.⁴ The central tracking system design therefore contains an electrical break near the middle. The current draw per wire at the operating gas gain of 2×10^4 is shown as a function of radius in Fig. 3(a); it is less than 0.35 μA /wire over the entire system and less than 0.15 μA /wire for radii beyond 150 cm at the SSC design luminosity of $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$. The occupancy as a function of radius is shown in Fig. 3(b); it is less than 5% over the entire system and less than 2% at large radii at the SSC design luminosity. These values should be multiplied by about a factor of two for curling tracks in a 2 Tesla magnetic field.

Two methods of support are being investigated. One method involves carbon-composite cylinders supporting each superlayer of straws. The other is based on a

(a)



(b)

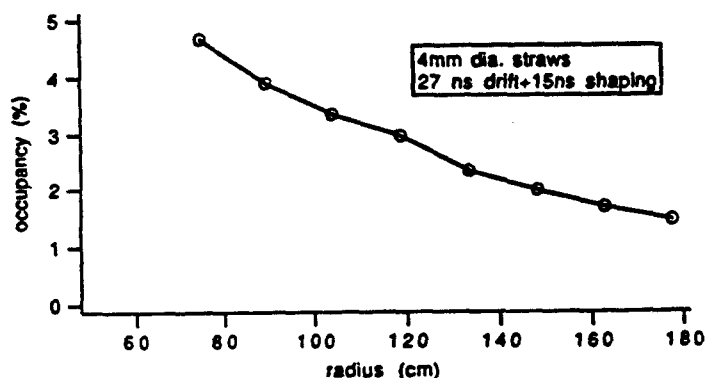


Fig. 3. (a) Current draw per wire *vs.* radius in the straw tube central tracking system for a gas gain of 2×10^4 at the SSC design luminosity. (b) Occupancy *vs.* radius in the straw tube central tracking system at the SSC design luminosity.

carbon-composite framework supporting replaceable modules of straws, as shown in Fig. 4.

There are 2.5×10^5 channels in the central tracking system. The amount of material traversed by a particle at normal incidence is 6%. There is additional material at the ends due to endplate wire supports and electronics, gas manifolds, high-voltage capacitors, and optical-fiber cabling.

1.4. Wire Chamber Intermediate Angle Tracking

For the intermediate angle tracking region ($1.3 \leq |\eta| \leq 2.5$) two approaches involving wires perpendicular to the beam direction are being considered. The

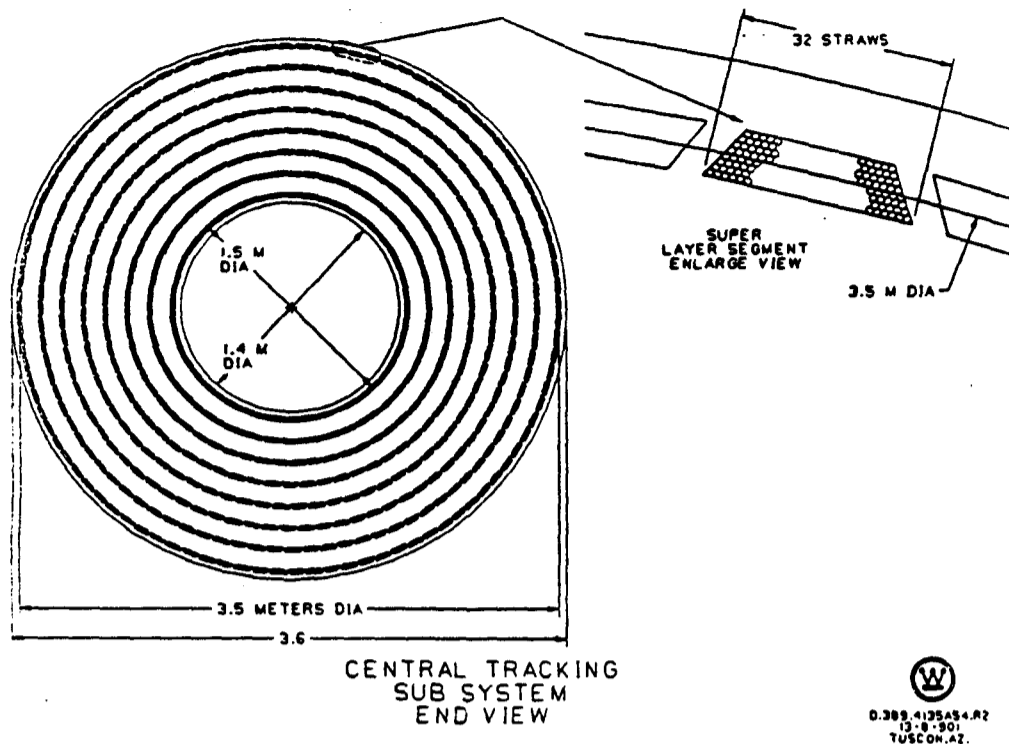


Fig. 4. Support system for replaceable modules of straws.

first employs crossed planar superlayers of straw tubes. The second involves the use of arrays of transverse drift cells which are optimized for fast track finding and reconstruction in a uniform axial magnetic field, much like the intermediate angle track detector in the H1 experiment at HERA⁵, shown in Fig. 5(a). In the latter this is efficiently achieved by means of radial sense wires, but the requirements both of a fast gas with large Lorentz angle and of high rate capability at the SSC mean that further consideration of the wire orientation is necessary; work is underway. Such a detector would contain about 300 azimuthal wedges to meet the constraints on current draw and occupancy over the full radial range. The coordinate along the wire will be measured with planes of wires tilted at small angles to the nominal wire direction, as shown in Fig. 5(b). The total number of channels for the intermediate angle tracking system is about 6×10^4 . An estimate of the percentage of a radiation length as a function of $|\eta|$ for the wire chamber central and intermediate angle tracking systems is shown in Fig. 6.

We anticipate readout of the pulse integral as well as timing from as many wires in the system as practical. This will extend the capability of the central and intermediate angle track detection to searches for particles with anomalous charge. Furthermore, if suitable radiator material is distributed throughout the wire chamber tracking volume between modules of either straw or other wire con-

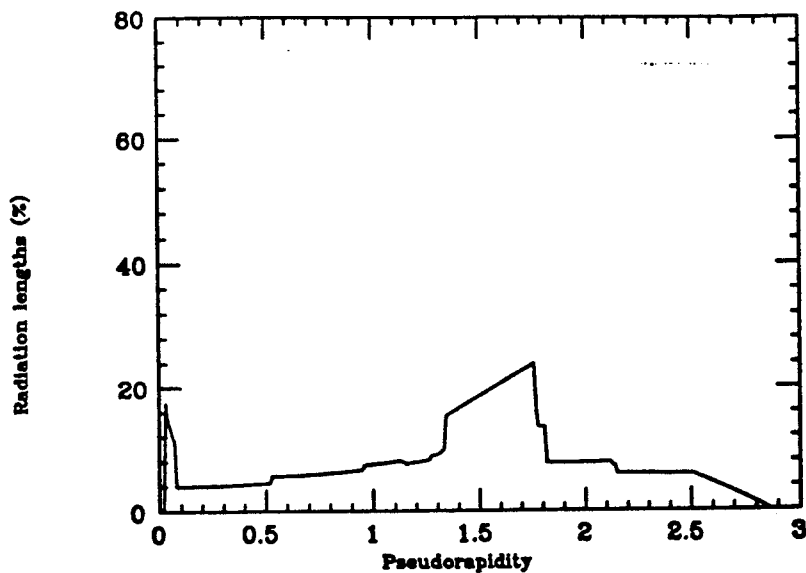


Fig. 6. Estimated percentage of a radiation length of material *vs.* $|\eta|$ for the straw tube central tracking system and the wire chamber intermediate angle tracking system.

2. WIRE CHAMBER ELECTRONICS

2.1. Front End Electronics

The wire chamber front end electronics will use radiation-hardened bipolar and/or CMOS technology. The drift time measurement resolution must be < 0.5 ns. The front end electronics consists of the following components:

- Preamplifier/shaper with signal tail cancellation
- Low power differential discriminator
- Time-to-voltage converter (TMC) and Analog Memory Unit with some trigger control⁷

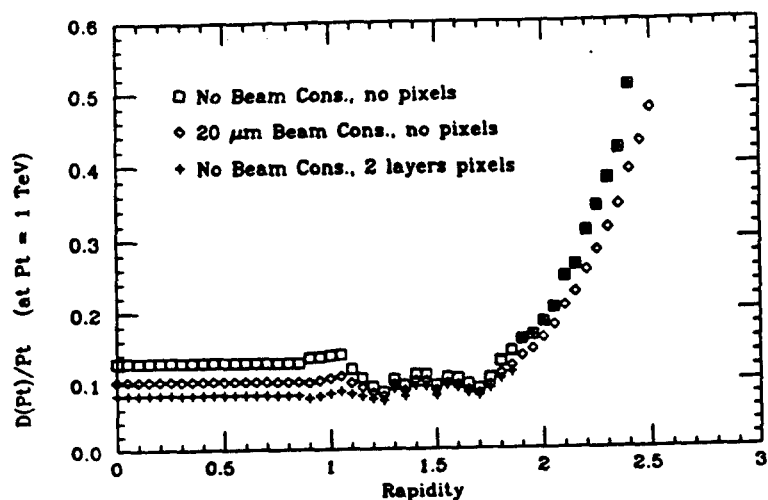
or

- Time Memory Cell (TMC) digital time measurement⁸
- Data collection chip

Figure 8 shows block diagrams for both the TMC and TVC designs, for both of which prototyping is well underway. Similar electronics can be used for radial wire chambers, for which there would be a 16 ns double-pulse resolution. Pulse integral measurements for transition radiation detection can also be incorporated.

One issue that is beginning to be addressed is the cost of the electronics for wire chambers. The electronics being designed, including time measurement and trigger, is located entirely on the chamber endplate, attached directly to the wires. Thus there isn't a cable for every channel going from the detector to crates of FASTBUS electronics. The data is buffered and read out over a small number

(a)



(b)

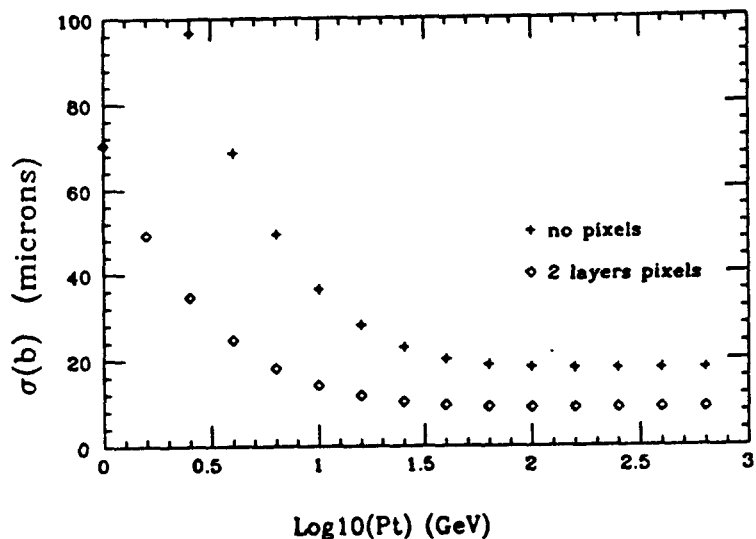


Fig. 7. (a) Momentum resolution in a 2 Tesla magnetic field as a function of $|\eta|$ for the proposed tracking system. (b) Impact parameter resolution as a function of momentum for the proposed tracking system.

of optical fibers. A preliminary cost estimate (not including the trigger) indicates a cost of less than \$35 per channel for TVC-based straw tube electronics.⁹

2.2. Track Segment Finding and Triggering

Track segments can be found locally in the superlayers. They can be characterized as local straight line segments since the sagitta over a superlayer is too small to measure for a relatively high p_T track. The two parameters characterizing a line segment could be the slope relative to a radial line at the track segment and the position given by the azimuthal angle. The slope is then a measurement of the p_T of the track. Since the radial extent of a superlayer of straw tubes is only about 3 cm, the displacement from a radial line is less than the cell width for a track with $p_T \gtrsim 10$ GeV/c in a 2 Tesla magnetic field. Thus drift times are

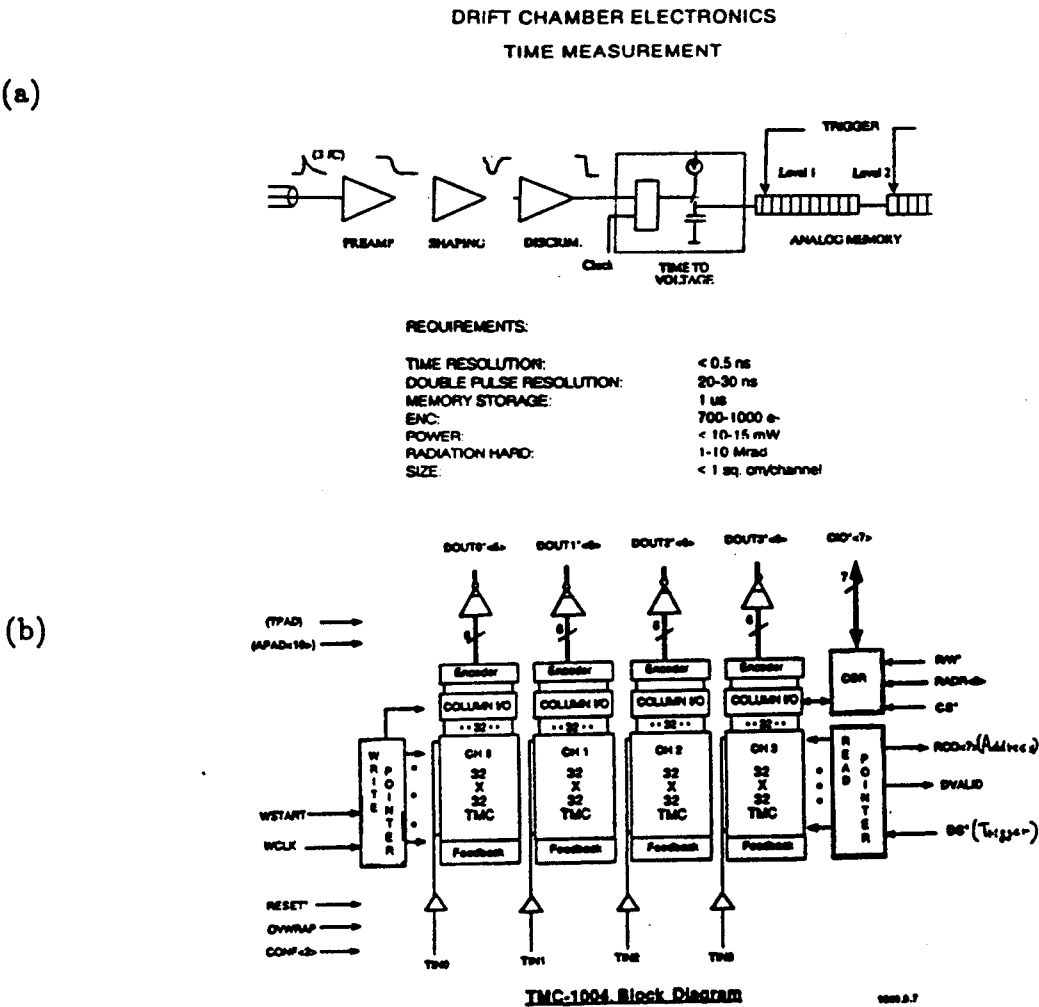


Fig. 8. (a) Block diagram for TMC-1004. (b) Block diagram for TVC-based front end electronics.

needed in the segment finding. An added complication is the need to have an estimate of the position of the track along the length of the wire since the propagation time is about 10 ns. Once track segments are found, they can be matched to clusters in the calorimeter, for example. Electronics is being developed to find the track segments with p_T larger than some cutoff value, for example, the synchronizer design of J. Chapman.¹⁰ Similar efforts are taking place in Japan. These track segments can then be used in the trigger, possibly even at the first level.

The coordinate (z-coordinate) of a track along a superlayer parallel to the beam direction may be found by measuring the displacement of the track seg-

ments between the axial and stereo superlayers (provided the linking can be accomplished). For this purpose one would not even have to use the drift times, although if the track is subject to a high- p_T cut this would probably be done using the track segments found in the trigger electronics. With 3° stereo, the displacement for a 3-m-long wire would be within ± 7.9 cm. Since the radius of the cell is 2 mm, this technique gives a resolution in z of 3.8 cm, which corresponds to ~ 0.1 ns propagation time.

3. RESEARCH AND DEVELOPMENT ISSUES

There are many questions that must be answered before we can arrive at a final design for an integrated silicon and wire chamber tracking system. Much of the R&D is being carried out in several SSC subsystem and generic programs.^{1,2,11,12,13} Some of the relevant research is summarized below.

The viability of the pixel and silicon strip system that occupies the inner part of the tracking volume depends on the resolution of such issues as fabrication technology, circuit design, radiation hardness, mechanical and thermal stability, precision alignment, adequate heat removal and ease of assembly.

For the outer part of the tracking volume, wire chamber technology is mature, although its application in the SSC environment poses unprecedented challenges. Research and development areas include minimizing material in the supports and end regions, incorporation of electronics, gas manifolds and high voltage distribution, precision alignment, and thermal management. Also included are the investigation of a hexagonal cell option, which might decrease the amount of material and improve the assembly procedure, and the R&D specific to the intermediate angle tracking system.

Research and development in the areas of front end, data acquisition and triggering electronics for the various components of the tracking system is advancing.

Engineering design leading to an integrated low-mass support system incorporating the necessary precise alignment is beginning. In addition, engineering design leading to the integration and assembly of the tracking system into the overall detector is being proposed. This includes evaluation of the mechanical support structures, integration of the tracking system components, cabling and power distribution, and development of the assembly, maintenance, and repair procedures.

4. POSSIBILITIES FOR HIGH-LUMINOSITY PERFORMANCE

Computer simulation studies of track segment finding have been carried out for the tracking system design for the "Large Solenoid Detector"¹⁴ at the SSC design luminosity of $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$. These simulations¹⁵ included background from minimum bias events within the resolving times of the cells, interactions of the particles with the material in the tracking system, curling tracks in a 2 Tesla magnetic field, and loss of hits due to the double-hit resolution. Over 80% of the track segments in the outer superlayers were found for high- p_T e 's and μ 's from Higgs boson decays with a crude segment-finding algorithm. Since that tracking system was designed, improvements have been made because of detector R&D efforts. These new developments have been incorporated in the design of the tracking system described here:

- The outer radius of the tracking system has increased from 1.5 to 1.8 m.
- Since there is a break in the wires in the middle due to signal attenuation, the rapidity range covered by a wire has decreased by about a factor of two.
- In the previous design, the cell width for the outer superlayers was nearly 7 mm. In the present design 4 mm diameter cells are used throughout.
- The old simulation used a drift velocity of $50 \mu\text{m/ns}$. Since that time fast gases with drift velocities $\sim 100 \mu\text{m/ns}$ have been shown to work.⁴

The relevant proportionality factors are given by

$$\text{Occupancy} \propto \frac{\eta_{\text{max}} n_B w}{r},$$

where η_{max} is the rapidity coverage of the wire, n_B is the number of bunch crossings during the resolving time of the cell, w is the width of the cell, and r is the radius. For the outer superlayers the largest improvement has occurred in the factor n_B because of both the decrease in the cell diameter and the increase in the drift velocity. A comparison between the old design and the present one shows that n_B has decreased from 4.3 to 1.4. Including the other improvements (two factors of two), we find that the occupancy for the present design is only 8% that of the previous design! This means that track segment finding in the outer superlayers of the design described here should work as well at a luminosity of $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ as the old simulation for $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$. Of course, this will have to be checked with simulations. There are other factors involved in running such a straw tube system as described here at $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, such as the current draw per wire. Based on the scaling factors described above, the current draw for the present design is 18% that of the old design. Much more work is needed, but

there is reason to hope that at a luminosity of $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ the outer superlayers of the straw tube tracking system will not only survive but also still be usable for finding track segments and providing a trigger.

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REFERENCES

1. "SSC Detector R&D Proposal: Development of Technology for Pixel Vertex Detector," D. Nygren, contact person (1989).
2. "Subsystem R&D Proposal to Develop a Silicon Tracking System," A. Seiden, contact person (1989).
3. D. G. Cassel, G. G. Hanson *et al.*, "Report of the Central Tracking Group," *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Supercollider*, edited by R. Donaldson and J. Marz, Snowmass, CO, 1986, p. 377.
4. H. Ogren, "Progress Report from Straw Chamber Subgroup," in these Proceedings.
5. G. A. Beck *et al.*, "Radial Wire Drift Chambers for the H1 Forward Track Detector at HERA: Design, Construction and Performance," *Proceedings of the Wire Chamber Conference, Vienna, Austria, 1989*, Nucl. Instr. and Meth. A283, 471 (1989).
6. H. Grässler *et al.*, "Simultaneous Track Reconstruction and Electron Identification in the H1 Radial Wire Drift Chambers," *Proceedings of the Wire Chamber Conference, Vienna, Austria, 1989*, Nucl. Instr. and Meth. A283, 622 (1989); S. Ahlen *et al.*, "Proposal to Develop An Integrated High Rate Transition Radiation Detector for the SSC," SSC PC-011, October, 1989; B. Dolgoshein, "The Transition Radiation Detector for High-Lorentz-Factor Particle Identification at High-Luminosity Hadron Colliders," *Proceedings of the ECFA Study Week on Instrumentation Technology for High-Luminosity Hadron Colliders, Barcelona, Spain, 1989*, p. 650.
7. F. M. Newcomer *et al.*, "High-speed Bipolar Integrated Circuits for SSC Applications," *Proceedings of the Wire Chamber Conference, Vienna, Austria, 1989*, Nucl. Instr. and Meth. A283, 806 (1989).

8. Y. Arai, "Development of TMC Chip and Track Trigger," in these Proceedings; Y. Arai and T. Ohsugi, "TMC - A CMOS Time to Digital Converter VLSI," IEEE Trans. Nucl. Sci. NS-36, 528 (1989); Y. Arai, "A Time Measurement System at the SSC," *Proceedings of the Workshop on Triggering and Data Acquisition for Experiments at the Supercollider, Toronto, Canada, 1989*, SSC-SR-1039, p. 125.
9. F. M. Newcomer and R. Van Berg, "Straw Electronics Cost Summary," unpublished (1990).
10. J. Chapman, "Tracking Trigger," in these Proceedings; S. Kim, "Tracking Trigger Study," in these Proceedings.
11. "SSC Detector Subsystem Proposal: Central and Forward Tracking with Wire Chambers," G. Hanson, contact person (1989).
12. "SSC Detector Subsystem Proposal: A Hybrid Straw Tube/Scintillating Fiber Tracking System," A. Goshaw, contact person (1989).
13. S. Parker, "A Proposal to Develop a VLSI Pixel Device for Particle Detection," (1987).
14. G. G. Hanson, S. Mori, L. G. Pondrom, H. H. Williams *et al.*, "Report of the Large Solenoid Detector Group," *Proceedings of the Workshop on Experiments, Detectors, and Experimental Areas for the Supercollider*, edited by R. Donaldson and M.G.D. Gilchriese, Berkeley, CA, 1987, p. 340.
15. G. G. Hanson, B. B. Niczyporuk and A. P. T. Palounek, "Wire Chamber Requirements and Tracking Simulation Studies for Tracking Systems at the Superconducting Super Collider," *Proceedings of the Wire Chamber Conference, Vienna, Austria, 1989*, Nucl. Instr. and Meth. A283, 735 (1989).